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MINERALOGY OF GOLD IN THE ROD MILL DISCHARGE AND IN THE FINAL COPPER CONCENTRATE FROM MINES NORTHGATE INC., CHIBOUGAMAU, QUEBEC

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MINERALOGY OF GOLD IN THE ROD MILL DISCHARGE AND IN THE FINAL COPPER CONCENTRATE FROM MINES NORTHGATE INC., CHIBOUGAMAU, QUEBEC

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ABSTRACT

Gold in the as-received Northgate mill products is present as native gold and electrum that occur as free particles and as grains variable from < 1 μm to several hundred μm. The grains are mainly associated with (i.e., attached to, or as inclusions in) pyrite; a small amount is associated with chalcopyrite which mostly is attached to pyrite grains. A trace amount of gold occurs as tiny grains, less than 2 μm, along the contacts between pyrite-sphalerite, and chalcopyrite-cobaltite. Only one gold grain was found associated with a quartz-chlorite composite grain. To increase net gold recovery, pyrrhotite can be rejected but pyrite and chalcopyrite must be retained. The final copper concentrate contains large amounts of silicates and carbonates, and also contains small amounts of magnetic minerals such as magnetite and pyrrhotite; these minerals occur mainly as free grains. The final copper concentrate can be up-graded and the gold recovery rate can be maintained if the magnetic and the non-metallic minerals are removed.

Keywords: gold, Mines Northgate Inc., mineralogy, final copper concentrate, rod mill discharge.

ÉTUDE DES PROPRIÉTÉS DE L'OR QUI SE TROUVE DANS LES DÉCHARGES DES BROYEURS À BARRES ET, CONCENTRÉ DE CUIVRE FINAL OBTENU À PARTIR D'UN PRODUIT PRÉSENTÉ PAR LES MINES NORTHGATE INC., DE CHIBOUGAMAU (QUÉBEC)

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T.T. Chen et J.M. Beaulne

RÉSUMÉ

Le minerai aurifère que renferment les déchets de concentrateur présenté par les Mines Northgate se présente sous forme d'or natif et d'électrum. Ces minéraux se retrouvent sous l'aspect de particules libres et de grains dont la dimension varie de 1 µm ou moins, à plusieurs centaines de µm. En général, les grains s'associent à la pyrite, soit en s'y fixant ou sous forme d'inclusions. Une faible quantité des grains est associée à la chalcopyrite qui, habituellement, se fixe sur les grains de pyrite. Une infime quantité d'or est présent sous forme de grains minuscules, d'une granulométrie de moins de 2 µm, qui se retrouvent autour des points de de contact de la pyrite-sphalérite et de la chalcopyrite-colbatite. On n'a retrouvé qu'un seul grain aurifère associé à un grain composé de quartz-chlorite. Par conséquent, afin d'augmenter les valeurs aurifères, la pyrrhotite peut être mise au rebut mais les autres minéraux sulfurés, en particulier la pyrite et la chalcopyrite doivent être conservées. Le concentré de cuivre final contient de grandes quantités de silicates et de carbonates. Il renferme également de petites quantités de minéraux ayant des propriétés magnétiques, telles la magnétite et la pyrrhotite qui se retrouvent principalement sous forme de grains libres. Le concentré de cuivre final peut être enrichi et le taux de récupération de l'or maintenu si on procède à l'élimination des minéraux magnétiques et non métallifères.

Mots-clé: or, les Mines Northgate Inc., minéralogie, concentré de cuivre final, décharge de broyeurs à barres.

INTRODUCTION

As part of the recent CANMET effort to assist the gold mining industry in Quebec, the mill operation at Mines Northgate Inc., Chibougamau, Quebec, was investigated. CANMET was asked to evaluate the possibility of improving gold recovery and/or up-grading the mill concentrates.

August 1987, when the samples were taken, more revenue was being derived from the gold than from the copper; since then, however, the price of copper has increased by about 50% thus narrowing the difference in revenue between the two. The ore was originally mined for copper. The feed to the rod mill contains approximately 4 ppm gold; after the combined operation of gravity concentration and flotation concentration, the gold content in the final tailings is reduced to approximately 0.34 ppm. Gravity concentration of rod mill and ball mill discharges recovers approximately 18% of the total gold, mainly as coarse native gold particles; the remainder is recovered in the copper concentrate. The company reported that, to obtain optimum gold recovery, it was necessary to recover pyrite in the copper concentrate; it also was mentioned that a mineralogical study done by Centre de Recherches Minerales, Saint-Foy, Quebec, showed that some gold was associated with pyrite. The amount of the pyrite in the copper concentrate adversely affects the grade of the copper concentrate. The freight and smelting costs incurred by shipping the so-produced low-grade copper concentrate to the smelter offset some of the revenue gained by the increase in gold recovery. Mines Northgate Inc. was satisfied with its gold recovery, but desired improvement in the grade of copper concentrate without sacrificing the gold recovery.

As the most fundamental part of the investigation, the mineralogy of the gold in the mill products was studied. The objective was to determine the modes of occurrence, textures, and mineral associations of gold in the ores, and to relate these features to ore beneficiation.

EXPERIMENTAL

Rod mill discharge, final copper concentrate, and scavenger tailings provided by Mines Northgate Inc. in late August 1987 were studied. Partial analyses of these samples are given in Table 1.

Table 1 - Partial Assays of Northgate Mill Products

	Au (ppm)	Cu%	Fe%	S%	Acid. insol.%	SiO_2%
Rod mill discharge	3.8	1.69	25.49	9.68	-	-
Final Cu conc.*	39.3	18.40	31.68	31.13	8.70	5.98
Scav. tailings	1.0**	0.03	24.79	7.60	-	-
Pyrite conc. (1.5A NM, 3.3 sink from final Cu conc.)	200	1.80	45.20	-		
Pyrite conc. (1.5A NM, 3.3 Sink from rod mill discharge)	23.6	0.55	-	-		

* Contains also CO_2 1.8%.

** This value possibly is inaccurate.

The as-received samples were screened into four size fractions: +100 mesh, -100+150 mesh, -150+270 mesh and -270 mesh. Each fraction was treated with heavy liquid of density 3.3 g/cm³ to produce a silicate-rich float and a sulphide-rich sink. The sink fractions were further separated by using a Franz magnetic separator to obtain magnetic (magnetite, pyrrhotite) fractions, siderite and ankerite-rich fractions, chlorite- and chloritoid-rich fractions, a chalcopyrite-rich fraction, and a pyrite- and quartz-rich fraction. More than 25 different fractions were prepared from each mill product. These fractions, as well as the original materials, were subjected to detailed mineralogical examination using ore microscopy, X-ray powder diffraction, and electron microscopy to determine the gold-carriers. It was found that the modes of occurrence of gold are the same in all four size fractions, i.e., almost all the gold particles were found in the pyrite-rich fractions, regardless of their sizes (i.e., the 1.5A non-magnetic, 3.3 sink fraction at all mesh sizes). Gold occurs as free

particles, as particles attached to pyrite, and as inclusions in pyrite. Of the more than 40 native gold (and electrum) particles found, only one is attached to quartz and chlorite, another is associated with chalcopyrite and cobaltite, and all others are either related to pyrite, or are associated with chalcopyrite attached to pyrite. The gold-associated chalcopyrite seems to fill fractures in the pyrite grains.

FINAL COPPER CONCENTRATE

The as-received material consists of major amounts of chalcopyrite, pyrite, chlorite (chamosite), chloritoid, siderite, minor amounts of quartz, ankerite, pyrrhotite, magnetite, and trace amounts of calcite, clinozoisite, muscovite, cobaltite, sphalerite, monazite and a Bi-Te mineral. Pentlandite (as inclusions in pyrrhotite) and apatite (associated with calcite and pyrite) were also identified. Figure 1 shows the general mineralogy of the final copper concentrates, and Figure 2 shows the detail of the mineralogy. Gold occurs as native gold (with a minor amount of solid-solution silver) and as electrum that are present mainly as: 1) free particles variable in size (4x10 to 40x200 μm; Figure 3), and 2) particles (several to 10x40 μm) attached to pyrite grains (Figure 4). A small amount occurs as electrum attached to pyrite-chalcopyrite composite grains (Figure 5), and one tiny grain (less than 2 μm) occurs between the grain boundary of pyrite and sphalerite (Figure 6). The gold particles are found both in the as-received final copper concentrate, and in the pyrite-rich fraction (1.5A non-magnetic, 3.3 sink) prepared from the as-received sample (Figure 7). Gold particles have not been found in the chalcopyrite-rich fraction (1.5A magnetic, 3.3 sink) prepared from the final copper concentrate, nor in the carbonate-rich (siderite, ankerite, etc.), the silicate-rich, the magnetite, and the pyrrhotite-rich fractions.

ROD MILL DISCHARGE

To confirm that gold in the mill products occurs as free particles and as particles mainly associated with pyrite grains, the as-received rod mill discharge was subjected to the aforementioned mineral seperation, and in

addition, a jig concentrate was prepared from the as-received material. It was found that most gold particles are present both in the pyrite concentrate (1.5A non-magnetic, 3.3 sink), and in the jig concentrate prepared from the as-received material; a trace amount is present in the chalcopyrite-rich fraction (1.5A magnetic, 3.3 sink). Gold particles were not found in the other fractions.

In the chalcopyrite-rich fraction, gold occurs as native gold (20x40 μm) along the contacts between chalcopyrite and cobaltite (Figure 8), and between pyrite and chalcopyrite. In the pyrite concentrate, gold is present mainly as native gold and electrum that occur as coarse free grains, as smaller particles (approximately 20x30 μm) attached to pyrite, and as inclusions in pyrite (Figure 9) and in pyrite-chalcopyrite composite grains. One electrum particle (10x10 μm) was found in association with a quartz-chlorite composite grain (Figure 10). In the jig concentrate, gold was found as native gold and electrum particles, a few micrometers to approximately 20x75 μm in size, attached to or included in pyrite grains. Gold grains occurring as inclusions in chalcopyrite and in chalcopyrite-pyrite composite grains are also common (Figure 11, 12); the gold in this association is present mainly along the contacts of pyrite and chalcopyrite which occur in composite grains (Figure 13). The assemblage of native gold and chalcopyrite occurs as fracture-fillings in pyrite grains (Figure 14, 15). The jig concentrate consists of composite grains, mainly pyrite, and traces of silicates, carbonates and chalcopyrite, all with grain sizes generally greater than 400x400 μm. A large number of the gold particles in the rod mill discharge is found in this jig concentrate.

SCAVENGER TAILINGS

Brief ore microscopic studies were conducted on the as-received scavenger tailings and on the Mozely table concentrate (7 minutes) and Mozely table tailings prepared from the as-received material. However, no gold particles were observed in these samples.

PYRITE CONCENTRATE

Table 1 shows that the pyrite fraction prepared from the final copper concentrate contains 200 ppm Au, compared to 39.3 ppm Au present in the original final copper concentrate. Similarly, the pyrite fraction prepared from the rod mill discharge contains 23.6 ppm Au, compared to 3.8 ppm Au carried by the original rod mill discharge. This means that gold in the as-received Northgate mill products is mainly associated with pyrite, and that most of the gold-associated pyrite grains have floated with the chalcopyrite and have reported to the final copper concentrate. Although high-grade (45.20% Fe) pyrite concentrate was obtained by this study, it is unlikely that in the commercial milling process such a high-grade product can be obtained without substantial extra operational costs.

CONCLUSIONS

1) Gold in the as-received Northgate mill products is present as native gold and electrum that occur as free particles and as grains, < 1 μm to several hundred μm, associated with pyrite and chalcopyrite. To increase recovery of the gold values, pyrite and chal copyrite must be retained.

2) In general, gold is not associated with silicates, carbonates, magnetite or pyrrhotite. These minerals are present mainly as free grains in the as-received mill products.

3) In the as-received final copper concentrate, gold is present as coarse-grained free particles and as grains associated with pyrite, or chalcopyrite which in most cases is attached to pyrite. The final copper concentrate contains large amounts (approximately 15% in total) of silicates and carbonates, and small amounts of magnetite and pyrrhotite. These minerals occur mainly as free particles in the mill products. The final copper concentrate can be up-graded and the gold recovery rate can be maintained if the magnetic and non-metallic minerals are removed.

4) Gold particles have not been observed in the Mozely table concentrate prepared from the as-received scavenger tailings. Most of the gold-attached pyrite grains evidently have floated with the chalcopyrite and have reported to the final copper concentrate; in contrast, the gold-free pyrite grains have been rejected during flotation and have reported to the scavenger tailings.

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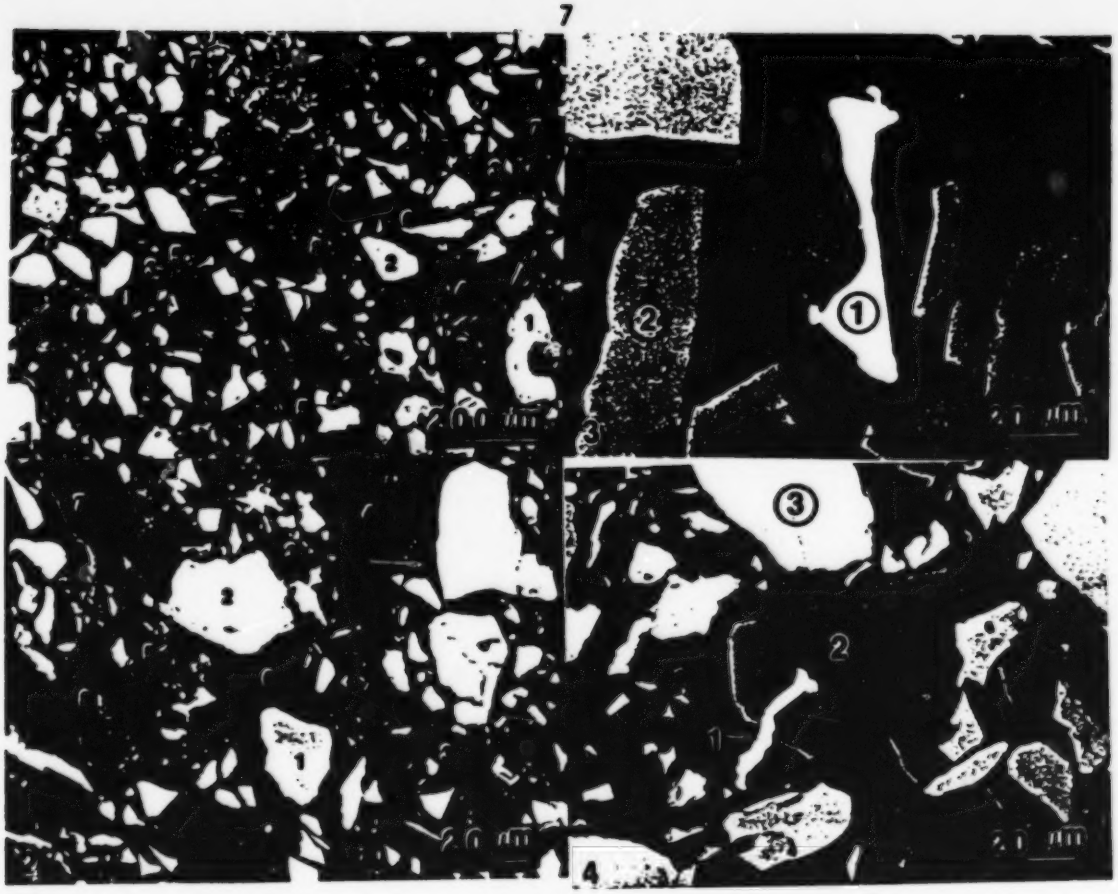

Fig. 1 - Backscattered electron micrograph (BSE) showing the general mineralogy of the final copper concentrate. 1 - chalcopyrite, 2 - pyrite, 3 - siderite, 4 - ankerite, 5 - quartz, 6 - mica, 7 - chlorite, 8 - chloritoid.

Fig. 2 - BSE photo showing the detailed mineralogy of the final copper concentrate. 1 - pyrite, 2 - chalcopyrite, 3 - chlorite, 4 - ankerite, 5 - chloritoid, 6 - quartz, 7 - siderite, 8 - sericite.

Fig. 3 - BSE photo showing the presence of free electrum particle in the final copper concentrate. 1 - electrum, 2 - chalcopyrite.

Fig. 4 - BSE photo showing the association of electrum and pyrite in the final copper concentrate. 1 - electrum, 2 - pyrite, 3 - chalcopyrite.

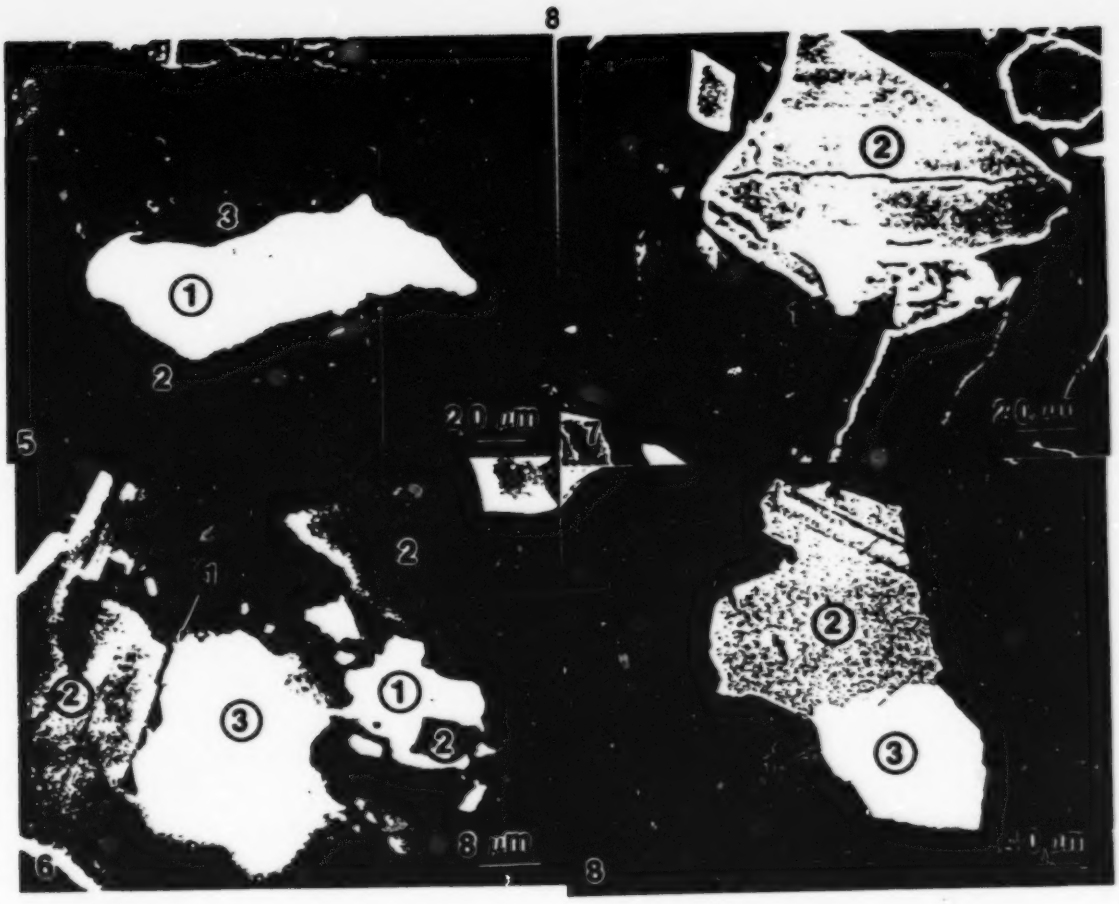

Fig. 5 - BSE photo showing the association of electrum (1) with pyrite (2) and chalcopyrite (3) in the final copper concentrate.

Fig. 6 - BSE photo showing the association of electrum (1) and pyrite (2), and electrum along the contact of pyrite and sphalerite (3) in the final copper concentrate.

Fig. 7 - BSE photo showing the association of electrum (1) with pyrite (2) in the pyrich-rich fraction (1.5 A non-magnetic, 3.3 sink) of the final copper concentrate.

Fig. 8 - BSE photo showing that native gold (1) occurs along the contact of chalcopyrite (2) and cobaltite (3) in the chalcopyrite-rich fraction (1.5A magnetic, 3.3 sink) of the rod mill discharge.

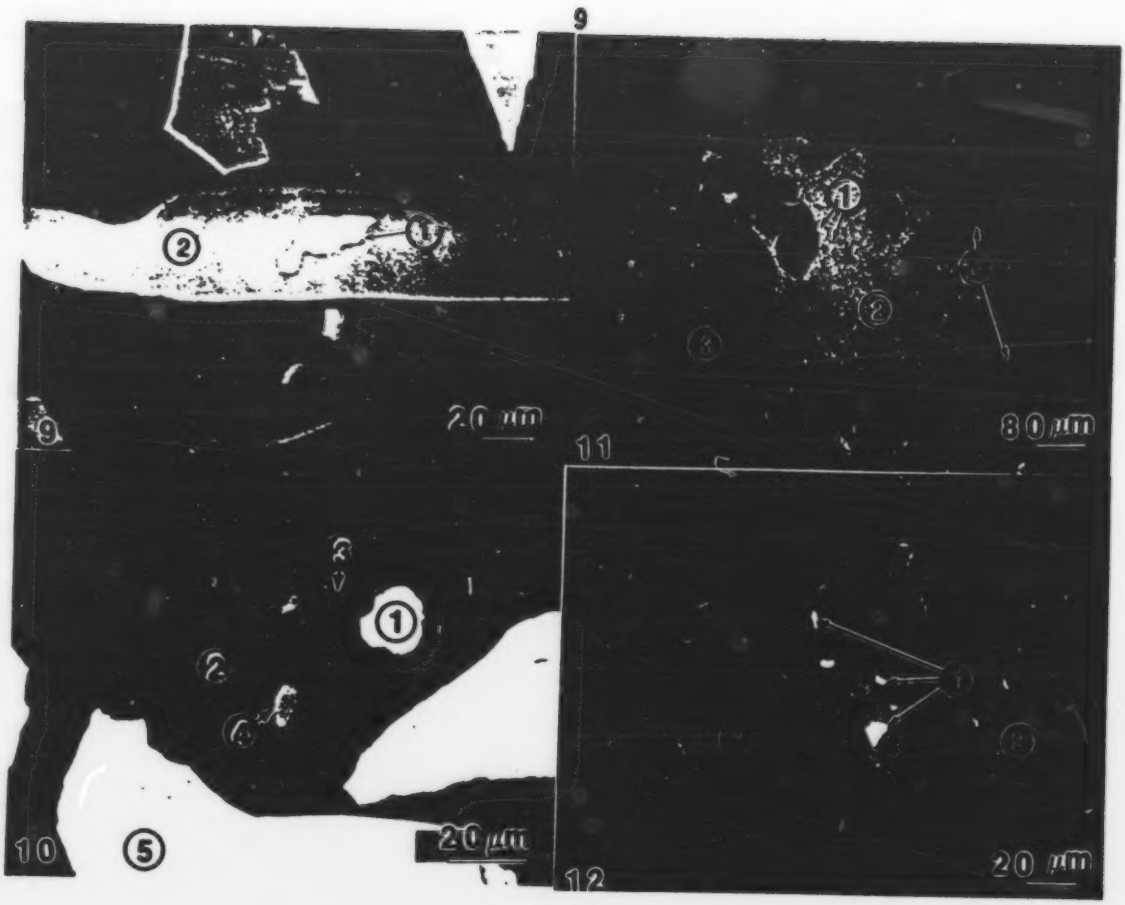

Fig. 9 - BSE photo showing native gold (1) as an inclusion in pyrite (2) in the pyrite-rich fraction (1.5A non-magnetic, 3.3 sink) prepared from the rod mill discharge.

Fig. 10 - BSE photo showing the association of electrum (1), quartz (2) and chlorite (3) in the pyrite-rich fraction (1.5A non-magnetic, 3.3 sink) of the rod mill discharge. 4 - siderite, 5 - pyrite.

Fig. 11 - BSE photo showing tiny electrum particles (1) in a chalcopyrite (2) - pyrite (3) - pyrrhotite (4) composite grain in the jig concentrate.

Fig. 12 - BSE photo showing the detail of the electrum inclusion (1) in chalcopyrite (2) - pyrite (3) - pyrrhotite composite grain shown in Fig. 11.

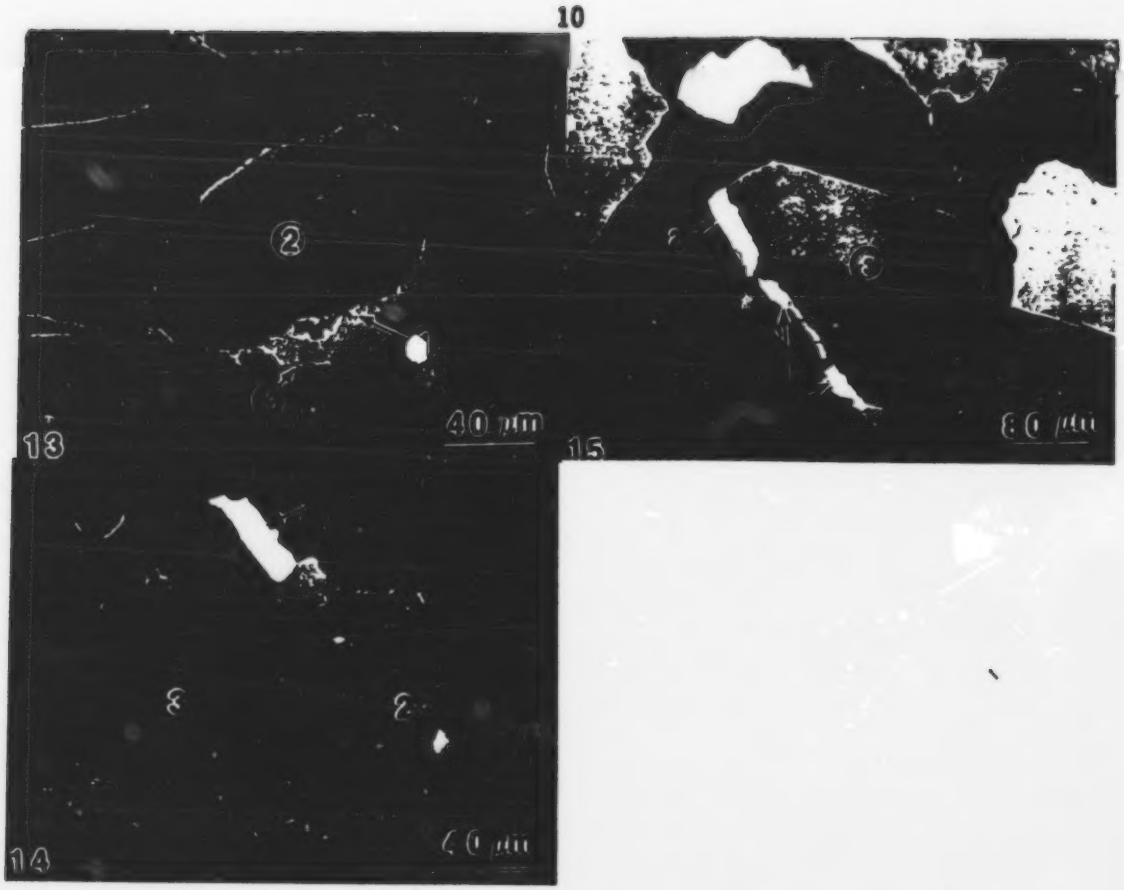

Fig. 13 - BSE photo showing electrum (1) along the contact of pyrite (2) and chalcopyrite (3) in the rod mill discharge.

Fig. 14 - BSE image showing native gold (1) and chalcopyrite (2) as fracture-fillings in pyrite (3) in the jig concentrate prepared from rod mill discharge.

Fig. 15 - BSE image showing native gold (1) and chalcopyrite (2) as fracture-fillings in a pyrite grain (3) in the jig concentrate prepared from rod mill discharge.